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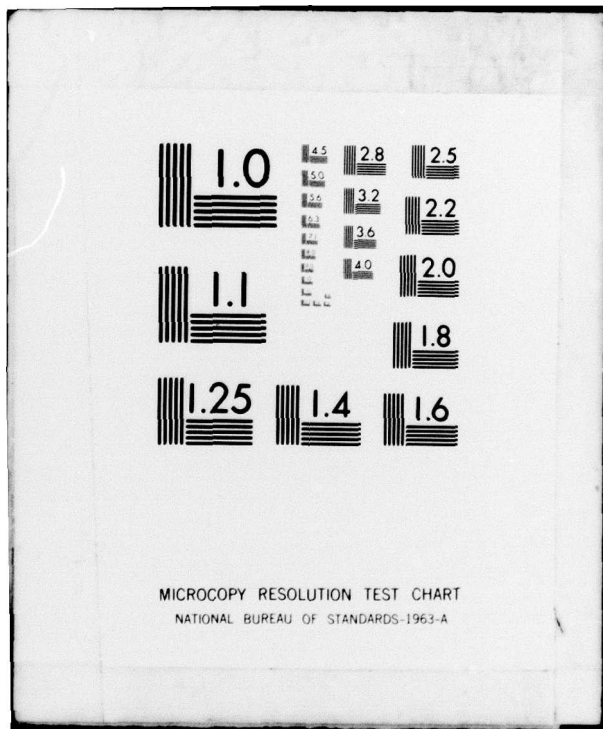
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WITH A PERIOD OF 160 MINUTES**

by

P.H. Scherrer, J.M. Wilcox,  
A.B. Severny, V.A. Kotov, T.T. Tsap

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In this letter we present some new data concerning 160-minute solar oscillations. We report conclusions based on observations made at the Crimean Astrophysical Observatory and the Stanford Solar Observatory during 1979. Oscillations of the sun with a period of about 160 minutes have been reported by Severny et al.<sup>1</sup> and further described by Kotov et al.<sup>2</sup> Scherrer et al.<sup>3</sup> reported the results of observations at Stanford for 1976 through 1978 and found that the Stanford observations tended to confirm the Crimean finding. The observations have been continued at both observatories with continuous agreement and improved statistical certainty.

The existence of such long-period oscillations would lead to an important increase in our knowledge of the internal structure of the Sun and make possible "solar seismology". Originating in the deep interior of the sun the oscillations seem to be capable of transferring a large amount of energy from the interior to the surface, an effect which should probably be taken into consideration in current theories of solar interior and may be related to the neutrino and angular-momentum problems of the Sun.

The oscillations are observed using similar methods at the two observatories. The observation is made by measuring the difference in line-of-sight velocity between the central area of the solar disk and a surrounding annular region. In 1979 the sun was observed in this way on 38 days (for 246 hours) in the Crimea and for 35 days (227 hours) at Stanford.

The data were analysed in the same way as in previous work<sup>3</sup> by computing the superposed epoch average curve with a period of 160.00 minutes. A least-squares best fit sinusoidal curve was then found for the average curve. Since 160 minutes is an exact fraction of a day the phase of the best fit sinusoid can be specified as a time.

For 1979 the time of maximum expansion (of the center of the solar disk) was found to be 01:55 U.T. for the Crimean observations and 01:58 U.T. for Stanford with a phase uncertainty of  $\pm 15$  minutes. The harmonic amplitudes of the mean curves were 0.37 m/s (Crimea) and 0.29 m/s (Stanford). Despite some difference in calibration and calculated sensitivity (factors 1.68 and 1.00 for Cr. and St. resp., for radial pulsations) which can produce the difference in amplitudes, the mean superposed epoch curves are in satisfactory agreement.

In Figure 2 of the previous report<sup>3</sup> we showed the phase of maximum expansion for each observatory for each year. The 1979 data has been added to this same figure and is shown here in Figure 1. The dashed line is an extrapolation of the regression line computed in the earlier paper. It can be seen that the 1979 points fall almost at the predicted phase.



The change in phase from year to year is consistent with an actual oscillation period of about 160.01 minutes rather than the 160.00 minute period used for the analysis. This difference in period is an important argument for the reality of the oscillations. Since 160 minutes is exactly  $1/9$  day it is to be expected that some signal at that period be found in the data.

It is very difficult, however, to conceive of any observational or statistical artifact that could produce such close agreement of phase with a period that is not exactly  $1/9$  of a day (see Fossat and Grec<sup>4</sup>).

Using all six years of data, a new regression line can be found which yields a period of 160.01 minutes or a drift in phase of 31.5 minutes/year in an analysis at exactly 160 minutes. Figure 2 shows the superposed epoch curves for both observatories using all the available data (1974-1979). This figure was prepared using a period of 160.010 minutes (with a reference time of 00<sup>h</sup>00<sup>m</sup> U.T. Jan. 1, 1974). This figure represents a significant amount of observing time, 715 hours for Stanford and 1407 hours for the Crimean Observatory. The formal statistical uncertainty in the amplitude of these curves is negligible ( $2A/\sigma \approx 7$ ) in both cases.

As before, we see from Figure 2 that the phase of the Crimean data is about 5 minutes earlier than for Stanford. If there were some terrestrial phenomena (e.g., effect from atmospheric transparency or other) related to the time of local solar noon, the Crimean phase would be 15 minutes after that for Stanford and would not change from year to year in the 160 minutes analysis.



The continued agreement in phase (and amplitude) between the two observatories as well as the fact that the period differs from exactly  $1/9$  of a day supports the interpretation that we are indeed observing solar oscillations.

While the average oscillation is steady, inspection of the individual records show that the observable amplitude varies from day to day and from year to year so the oscillations can almost disappear for some time as has been noted also by Isaak et al.<sup>5</sup> This may be due to masking of the oscillations by other motions in surface layers of the Sun such as supergranulation, giant convective cells, etc. which spoil the regular pattern as was pointed out by Gough et al.<sup>6</sup> Also, the amplitude of oscillations can be modulated by the rotation of the Sun as noted by Severny et al.<sup>7</sup>

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We would like to thank Dr. D.N. Rachkovsky for the help in computer analysis of the data. This work was facilitated by a visit P.H. Scherrer to the Crimean Astrophysical Observatory. At Stanford University, this work was supported, in part, by the Office of Naval Research under Contract N00014-76-C-0207, by the National Aeronautics and Space Administration under Grant NGR 05-020-559 and Contract NAS5-24420 and by the Division of Atmospheric Sciences, Solar-Terrestrial Research Program of the National Science Foundation under Grant ATM77-20580.

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### Figure Captions

- Figure 1      The time of maximum expansion in minutes from 0 U.T. for Stanford observations (S) and Crimean observations (C). The phase is computed from a harmonic analysis. The error bar shows the typical uncertainty in phase. The line was computed using only 1974-1978 observations. The dashed portion is an extrapolation.
- Figure 2      Superposed epoch plots of the Stanford and Crimean observatories with a folding period of 160.01 minutes. The phase is defined to be 0 at 0 U.T. on January 1, 1974. The harmonic amplitude and phase for Stanford and the Crimean data are 0.22 m/s, 18 minutes and 0.54 m/s, 13 minutes respectively.



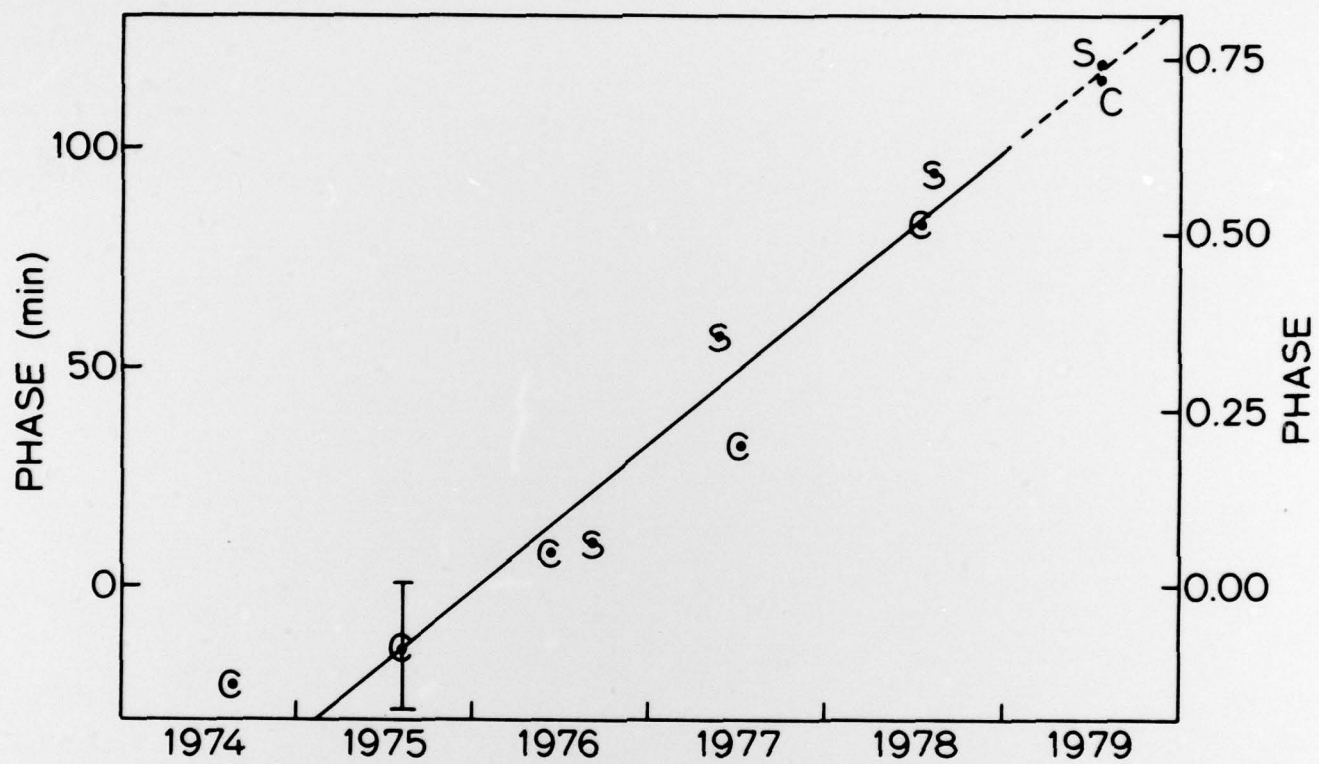


Figure 1

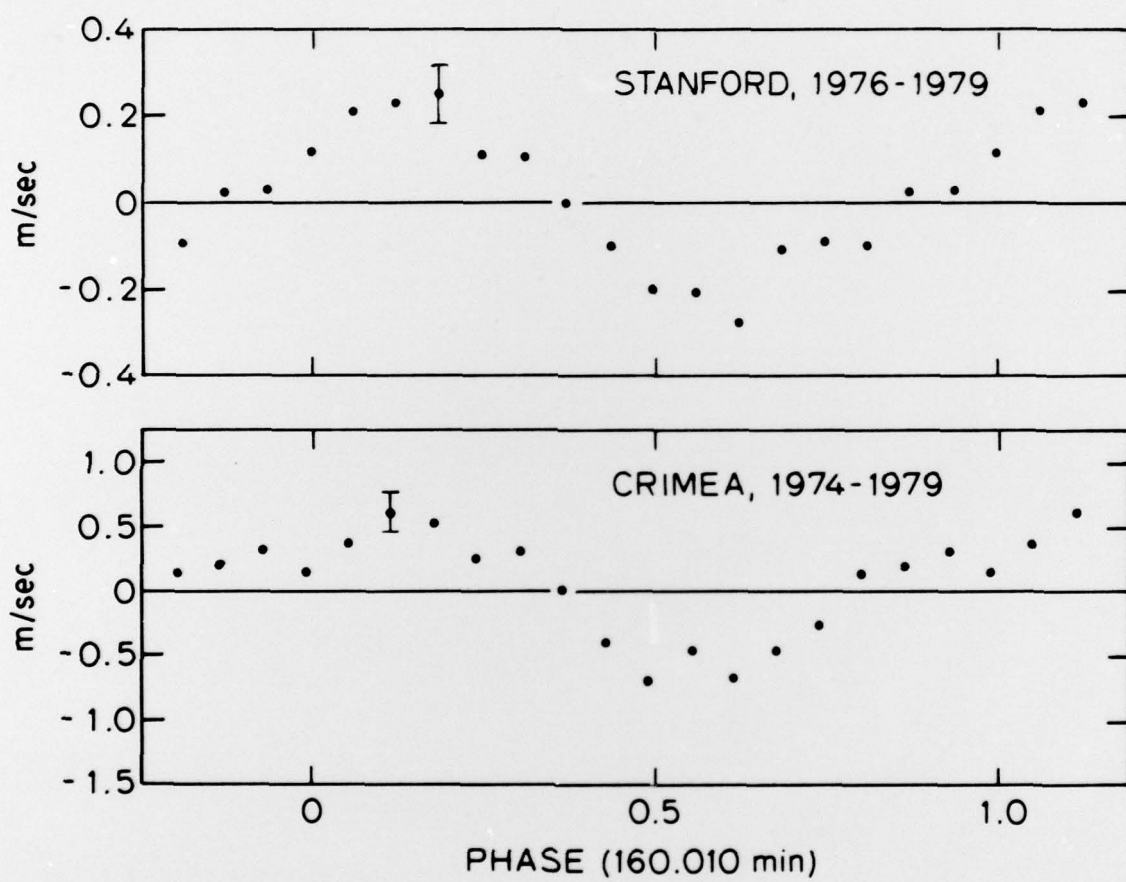


Figure 2